Children's annoyance reactions to aircraft and road traffic noise

Elise E. M. M. van Kempen,[a] Irene van Kamp,[b] and Rebecca K. Stellato[c]
National Institute for Public Health and the Environment, Centre for Environmental Health Research, P.O. Box 1, 3720 BA Bilthoven, The Netherlands

Isabel Lopez-Barrio[d]
Institution de Acustico, Consejo Superior De Investigaciones Cientificas (CSIC), C/Serrano 144, E-28006 Madrid, Spain

Mary M. Haines[e]
The Sax Institute, 235 Jones Street, Ultimo, Sydney, New South Wales 2000, Australia

Mats E. Nilsson[f]
Department of Psychology, Institute of Environmental Medicine, and Karolinska Institute, Stockholm University, SE-106 91 Stockholm, Sweden

Charlotte Clark[g]
Barts and the London, Queen Mary's School of Medicine and Dentistry, University of London, London EC1M 6BQ, United Kingdom

Danny Houthuijs[h]
National Institute for Public Health and the Environment, Centre for Environmental Health Research, P.O. Box 1, 3720 BA Bilthoven, The Netherlands

Bert Brunekreef[i]
Institute for Risk Assessment Sciences (IRAS), and Julius Center for Health Sciences and Primary Care, University Medical Center Utrecht, University of Utrecht, P.O. Box 80178, 3508TD Utrecht, The Netherlands

Birgitta Berglund[j]
Department of Psychology, Institute of Environmental Medicine, and Karolinska Institute, Stockholm University, SE-106 91 Stockholm, Sweden

Stephen A. Stansfeld[k]
Barts and the London, Queen Mary's School of Medicine and Dentistry, University of London, London EC1M 6BQ, United Kingdom

(Received 10 June 2008; revised 27 October 2008; accepted 6 December 2008)

Since annoyance reactions of children to environmental noise have rarely been investigated, no source specific exposure-response relations are available. The aim of this paper is to investigate children's reactions to aircraft and road traffic noise and to derive exposure-response relations. To this end, children's annoyance reactions to aircraft and road traffic noise in both the home and the school setting were investigated using the data gathered in a cross-sectional multicenter study, carried out among 2844 children (age 9–11 years) attending 89 primary schools around three European airports. An exposure-response relation was demonstrated between exposure to aircraft noise at school ($L_{Aeq,7–23\ h}$) and severe annoyance in children: after adjustment for confounders, the percentage severely annoyed children was predicted to increase from about 5.1% at 50 dB to about 12.1% at 60 dB. The findings were consistent across the three samples. Aircraft noise at home ($L_{Aeq,7–23\ h}$) demonstrated a similar relation with severe annoyance. Children attending schools with higher road traffic noise ($L_{Aeq,7–23\ h}$) were more annoyed. Although children were less annoyed at levels above 55 dB, the shapes of the exposure-response relations found among children were comparable to those found in their parents.
 [DOI: 10.1121/1.3058635]

PACS number(s): 43.50.Qp, 43.50.Lj, 43.66.Lj [BSF] Pages: 895–904

I. INTRODUCTION

Annoyance is one of the most widespread and well-documented responses to noise. It is a collective term for several negative reactions such as irritation, dissatisfaction, or anger, which appear when noise disturbs someone's daily activities.[1] While adult reactions to noise have been well described,[2–4] this is not so for noise annoyance in children. In comparison with adults, children may be particularly vulnerable to the effects of noise because they have less capacity to anticipate, understand, and cope with stressors.[5]

Exposure-response relationships for noise annoyance among adults have been widely studied, and large datasets have allowed the construction of generalized curves.[6–11] For children, generalized exposure-response relationships are lacking. According to Lercher,[12] this omission is due to a lack of a standard methodology for measuring annoyance in children and insufficient representative data on which to base a generalized exposure-response relationship. Four previous studies have assessed residential noise annoyance in children in a quantitative and systematic manner: the Munich airport study,[13,14] the Heathrow studies,[15–17] and the Tyrol studies.[18,19] In these studies, children living in noisier areas in their community were significantly more annoyed by noise than children living in quieter areas.

Most studies have only focused on exposure at school when investigating the effects of noise exposure in children. This is a gap in research since the impact of noise on children's health can occur in different environments over a 24 h period: at home and at school, indoors and outdoors and over different times of the day.[20]

Among adults, annoyance is usually measured by means of one or more questions as part of a questionnaire or interview.[21] In the past, a wide variety of questions and scaling methods has been employed to measure annoyance.[11] As with adult studies, different methods have been used to measure children's annoyance reactions. Although each of the studies purports to measure annoyance, it is not fully clear what is being measured. Some studies[13,14] define annoyance as an affective response that indicates a chronic decline in well-being; others[22] conclude that noise annoyance in children pertains to the same construct as in adults, since the emotional response to aircraft noise was consistent with adult reactions. In previous studies among adults,[23,24] interference and annoyance were highly related while well-being formed a separate dimension. It is uncertain whether children are also able to make such distinctions and thus show a comparable pattern to adults.

The primary goal of this paper is to investigate children's annoyance reactions and the existence of exposure-response associations to aircraft and road traffic noise in both the home and the school setting, using data collected from children living around three European airports, gathered in the framework of the European Fifth Framework Project Road Traffic and Aircraft Noise Exposure and Children's Cognition and Health (RANCH). A secondary goal was to compare children's annoyance reactions with those of their parents. Some results of RANCH have already been reported elsewhere,[25] focusing on the effects of noise exposure at school on cognition and health.

II. METHODS

A. Selection and recruitment

Children aged 9–11 years were recruited from primary schools in areas around Heathrow airport (London, UK), Schiphol airport (Amsterdam, The Netherlands), and Madrid-Barajas airport (Spain). Schools were selected according to the modeled noise exposure of the school area (expressed as $L_{Aeq,7–23\ h}$) and were matched on indicators of socioeconomic status (SES) and ethnicity. Out of 767 primary schools available, 134 were invited to participate and 89 agreed. The parents or caregivers of 3207 children were approached through the schools by letter to give consent for their children to participate. Written consent was additionally obtained from the children. The final sample contained 2844 children. For full details of selection and recruitment, see Ref. 25.

B. Procedure

The children completed a self-administered questionnaire on annoyance as part of a 2 h group testing session which also included various paper-and-pencil tests measuring cognitive abilities.[25] The children were also given a questionnaire to take home for one of their parents or caregivers to complete, and requested information on the health and behavior of the child, on hearing transportation sounds and their annoyance, and potential confounding factors such as glazing of the child's home, length of residency, indicators for SES (employment status, crowding, maternal education, and parental home ownership), ethnic origin, and main language spoken at home. These variables were only available for those children whose parents also completed the questionnaire, so parents' participation served as a criterion for inclusion in the statistical analysis. To ensure accurate conceptual translation, all questionnaires were translated from English into Dutch and Spanish and subsequently back-translated. Before data collection, all procedures and materials were tested in a pilot study in October 2001. In all three participating countries, ethical approval of the study was obtained.

[a]Author to whom correspondence should be addressed. Electronic mail: elise.van.kempen@rivm.nl
[b]Electronic mail: irene.van.kamp@rivm.nl
[c]Electronic mail: r.k.stellato@bio.uu.nl
[d]Electronic mail: iaclb41@ia.cetef.csic.es
[e]Electronic mail: mary.haines@saxinstitute.org.au
[f]Electronic mail: mnn@psychology.su.se
[g]Electronic mail: c.clark@qmul.ac.uk
[h]Electronic mail: danny.houthuijs@rivm.nl
[i]Electronic mail: b.brunekreef@iras.uu.nl
[j]Electronic mail: birber@mbox.ki.se
[k]Electronic mail: s.a.stansfeld@qmul.ac.uk

C. Noise exposure assessment

In each country, predicted levels of aircraft noise exposure for both the *school* and children's *home* address were obtained from nationally available noise contours or grids. The United Kingdom and Spain both used noise contours predicting $L_{Aeq,16\ h}$, which predicts average noise exposure from 0700 to 2300 h for a three month period for the year 2000. In The Netherlands, modeled aircraft noise levels ($L_{Aeq,7-23\ h}$) for the period of a year with a resolution of 250×250 m^2 grids were obtained. The contours in the UK and Spain were provided by the British Civil Aviation Authority and the Spanish Airports and Air Navigation, respectively. The Netherlands used noise data from the year 2001 provided by the Dutch National Aerospace Laboratory (NLR).

Road traffic noise levels were only available for the school situation since it was not possible to estimate road traffic noise exposure at home in a reliable way for this study. Predictions of road traffic noise at school (expressed in $L_{Aeq,7-23\ h}$) were made using different methods in each country, as the data detailing road traffic noise in each country varied enormously. In the UK, road traffic noise exposure was predicted using calculation of road traffic noise (CRTN).[26] This method involves obtaining the traffic flow data for the road section nearest to the school and calculating noise exposure. The traffic flow data covered the period 0700 to 2300 h. In The Netherlands, modeled composite data from 2000 and 2001, with a resolution of 25×25 m^2 grids, were linked to school addresses using a geographic information system (GIS).[27] In Spain, direct external measurements were taken of road noise during school visits. Taking into account factors such as traffic flow, speed limits, and distance to the street, these were transformed into 7–23 h L_{Aeq}-values.

D. Child and parent noise annoyance

For both children and parents, annoyance was measured as part of a self-administered questionnaire by means of standard questions. For children the following wording was used: "Thinking about the last year, when you are at [school] [home], how much does the noise from [aircraft] [road traffic] bother, disturb, or annoy you?" Answers were indicated on a five-point category scale ("not at all, a little, quite a bit, very much, extremely"). For parents the following wording was used: "Thinking about the last 12 months, when you are at home, how much does noise from [aircraft] [road traffic] noise bother, disturb, or annoy you?" Answers were indicated on a five-point category scale ("not at all, slightly, moderately, very, and extremely").[21]

Children and parents were also asked how frequently they heard the noise from road traffic or aircraft when they were at school or home: "Do you hear noise from [aircraft] [road traffic] when at [school] [home]?" Answers were indicated on a four-point category scale ("never, sometimes, often, and always"). If parents indicated never hearing noise while indicating "slightly," "moderately," "very," or "extremely" annoyed, their answer on the question measuring annoyance was recoded to "not at all annoyed." Since we could not necessarily expect children to answer these questions in such a consistent way, this transformation was not used for the children. For both children and parents, the answers of the annoyance questions were subsequently dichotomized, with the two highest categories ("very much" and extremely annoyed) defining "severely annoyed." This cutoff corresponds to a lower cutoff than used for defining "highly annoyed" in the pooled analyses of Miedema and co-workers.[9–11] In their analyses, the annoyance scale is transformed to a 0–100 scale and the cutoff for highly annoyed corresponds to a value of 72.[9–11] Our cutoff point would correspond to a cutoff at 60 on the same scale.

E. Interference with activities

Interference with activities at school and at home was measured by asking the children whether noise from road or aircraft noise interfered with (i) playing outdoors, (ii) working in a group, (iii) working individually, (iv) listening to the teacher, (v) listening to TV, radio, or music, (vi) talking, or (vii) reading or doing homework. Answers were indicated on a four-point category scale ("never, sometimes, often, and always").

F. Perceived health

In order to measure perceived health, the children were asked how often they had the following symptoms during the past month: headache, vomiting, stomachache, difficulty falling asleep, and the number of times woken at night or felt sleepy during the day. Answers were indicated on a five-point category scale ("never, a few times, once a week, a few times a week, and every day or night").

G. Data analysis

In order to test the convergent and divergent validity of the annoyance scale, a principal component analysis (PCA) was carried out using SPSS for Windows (version 12.0.1) on the annoyance and interference questions for both the school and home situation and perceived health. Home and school annoyance and interference questions were combined in the PCA, and subjective health symptoms were included, in order to determine whether children could distinguish between the home and school situation, and between annoyance interference and subjective health. We expected high correlations between annoyance and/or interference at school and at home for aircraft noise, respectively, but not necessarily for road traffic noise. Only components that accounted for variances with eigenvalues greater than 1 were included in the following presentation. To make the components more interpretable a rotation with the Varimax method was performed. However, on the basis of age, gender, etc., one would expect a certain correlation between the components. As a kind of sensitivity analysis an oblique rotation (with delta=0) was performed in addition to Varimax rotation, assuming that the resulting components may be correlated. Cronbach's alphas were calculated to test the internal consistency of the obtained components.

To assess the association between aircraft and road traffic noise exposure and severe annoyance, multilevel logistic regression analyses by means of generalized linear mixed models were carried out using the GLIMMIX procedure in SAS version 9.1. The advantage of multilevel modeling compared to a simple logistic regression approach is its ability to take into account effects at the level of center, school, and pupil simultaneously. Two-level (pupil and school) random intercept models were used, and country was included as a fixed effect. Coefficients (B) and standard errors were estimated under residual pseudolikelihood estimation. In all models, aircraft or road traffic noise exposure (either at school or at home) was the main independent variable and was included as a continuous variable. For the association with aircraft noise, a quadratic term for aircraft noise was also included because this increased the model fit (see also Ref. 25). The logistic regression models included age (years), sex, ethnicity (white/nonwhite), school glazing (single, mixed, double, and triple) or double glazing at home (yes/no), length of school enrolment (<1, 1–2, 3–6, and >6 years) or residency (<1, 1–5, 6–10, and >10 years), and indicators of SES (crowding, home ownership, parental employment, and mother's education) as potential confounders. Models were estimated for the pooled data. Heterogeneity in the exposure-response relationships among countries was tested in the models on the pooled data by examining the interaction between country and noise exposure. Statistical significance of a coefficient was tested under maximum pseudolikelihood estimation, using a Wald chi-square test.

III. RESULTS

A. Sample information

The British sample contains fewer employed parents, fewer home owners, and more nonwhite children than the Dutch and Spanish samples. The prevalence of severe annoyance due to aircraft and road traffic noise in the Dutch and Spanish samples was somewhat lower than in the British sample. There were also differences between the samples in terms of length of time at school and glazing (Table I).

B. Construct validity

The PCA on interference, annoyance, and perceived health yielded five components with eigenvalues greater than 1 (Table II). The total percentage of variance explained by these five components was 56%. The values of the Cronbach's alphas indicate that the components have a high reliability. Items referring to annoyance and interference from aircraft noise annoyance (without distinction between home and school situations) loaded highly on the first component, whereas items regarding annoyance and interference from road traffic noise at school loaded highly on the second component. Items referring to interference at home from road traffic noise loaded highly on the third component, and items on self-reported health symptoms loaded highly on the fourth component. Items loading highly on the fifth component referred to interference when playing outdoors at home, and school due to aircraft and road traffic noise, and annoyance from road traffic noise at home. The oblique rotation resulted in the similar grouping of variables as the Varimax rotation, and the interpretation of the components did not change.

C. Aircraft noise exposure *at school*

Aircraft noise exposure at school was significantly related to severe annoyance ($\chi^2=52.7$, $df=2$, $p<0.0001$): in schools in areas with higher aircraft noise exposure the proportion severely annoyed children was significantly higher. The percentage severely annoyed children was predicted to increase from about 5% at 50 dB to about 12% at 60 dB (Fig. 1). The only potential confounder that had a significant effect on annoyance was mother's education ($\chi^2=6.8$, $df=1$, $p=0.009$); children of mothers with a higher level of education were more annoyed by aircraft noise at school; an odd ratio (OR) of 2.24 (95%CI: 1.22–4.12) was estimated. Country did not have a significant effect on annoyance ($\chi^2=1.6$, $df=2$, $p=0.457$). Although the proportion of severely annoyed children in the Dutch sample was higher compared to the British and Spanish samples at aircraft noise levels ($L_{Aeq,7-23\ h}$) of 63 dB and higher, the change in the percentage severely annoyed per 1 dB increase in the noise did not differ significantly between the three countries (test of heterogeneity: $\chi^2=8.9$, $df=4$, $p=0.064$).

D. Aircraft noise exposure *at home*

Aircraft noise exposure at home was significantly related to severe annoyance ($\chi^2=50.5$, $df=2$, $p<0.0001$): the proportion of severely annoyed children was higher in areas with higher aircraft noise levels. The percentage severely annoyed children was predicted to increase from about 7% at 50 dB to about 15% at 60 dB (Fig. 2). Country did not have a significant effect on annoyance. The only potential confounder that had a significant effect on annoyance was gender: girls were less annoyed due to aircraft noise at home than boys ($\chi^2=8.3$, $df=1$, $p=0.004$) [OR=0.62 (95%CI: 0.45–0.86)]. The difference in the effect size at different noise levels for each country was statistically not significant (test of heterogeneity: $\chi^2=5.9$, $df=4$, $p=0.209$). Comparison between Figs. 1 and 2 indicates that the exposure-response relationships for the home and school situations are similar.

E. Road traffic noise exposure *at school*

Road traffic noise exposure at school was significantly related to severe annoyance from road traffic noise at school: children attending schools with higher road traffic noise were more annoyed ($\chi^2=7.4$, $df=1$, $p=0.007$). The percentage severely annoyed children was predicted to increase from about 4% at 50 dB to about 6% at 60 dB (see also Fig. 3). Potential confounders that had a significant effect on annoyance were mother's educational attainment ($\chi^2=16.6$, $df=1$, $p<0.0001$) [OR=5.04 (95%CI: 2.28–11.8)], school enrolment ($\chi^2=8.4$, $df=3$, $p=0.040$), and school glazing ($\chi^2=7.2$, $df=2$, $p=0.028$). There was no significant difference in the change in the percentage severely annoyed per 1 dB increase in the noise between the three countries (test of heterogeneity: $\chi^2=0.70$, $df=2$, $p=0.704$). Comparison between Figs. 1 and 3 indicates that the exposure-response re-

TABLE I. General characteristics of the children and their parents included in the analysis. (Abbreviations: *N*, sample size; SD, standard deviation;%, percentage; L_{Aeq},7–23 h, equivalent noise level from 7 to 23 h).

Characteristic	UK (*N*=863)	The Netherlands (*N*=612)	Spain (*N*=553)
No. of participating schools	29	33	27
Girls (%)	54.5	50.1	53.0
Mothers (%)	93.3	90.8	92.0
Mean age (SD)			
Children	10.3 (0.3)	10.5 (0.6)	10.9 (0.4)
Parents	37.7 (5.5)	40.9 (4.1)	39.6 (5.0)
Socioeconomic status			
Crowding in the home (%)	22.1	31.4	9.6
Parental home ownership (%)	59.4	81.7	85.5
Employed parents (%)	78.5	93.0	89.3
Mean mother's education (SD)[a]	0.5 (0.3)	0.5 (0.3)	0.5 (0.3)
White British/Dutch/Spanish (%)	66.2	89.4	91.5
Length of time at school (%)			
Less than 1 year	3.5	0.2	0.2
1–2 years	10.4	6.6	3.4
3–6 years	49.7	21.3	9.0
More than 6 years	36.5	72.0	87.5
Length of residence (%)			
Less than 1 year	7.0	4.1	7.1
1–5 years	33.8	19.8	21.3
6–10 years	26.7	19.3	17.5
More than 10 years	32.5	56.9	54.1
Severe annoyance (%)			
Aircraft noise at school, children	10.9	9.4	7.4
Aircraft noise at home, children	12.2	7.1	7.8
Road traffic noise at school, children	6.5	4.0	4.9
Aircraft noise at home, parents	11.6	8.7	6.2
Mean modeled noise exposure ($L_{Aeq,7–23\ h}$) levels [dB(A)] (range)[b]			
Aircraft noise at school	53.0 (34.0–68.0)	54.2 (41.0–68.0)	46.1 (30.0–77.0)
Aircraft noise at home	53.1 (33.9–72.8)	49.1 (34.5–64.5)	46.4 (31.9–72.8)
Road traffic noise at school	50.6 (37.0–67.0)	49.3 (34.0–62.0)	54.1 (43.0–71.0)
Insulation			
School glazing (%)			
Single	51.9	44.3	71.3
Mixed	9.0	–	–
Double	39.1	46.6	28.8
Triple	–	9.2	–
Double glazing at home (%)	82.2	58.1	57.1

[a]Ranked index of standard qualification in every country.
[b]The range runs from the minimum value to the maximum value.

lationships for road traffic noise and aircraft noise differ from each other: the relation with annoyance is much stronger for aircraft noise.

F. Comparison of childrens' and parents' annoyance reaction to aircraft noise

In Fig. 4 the exposure-response relationships for both children and parents are presented for the exposure to aircraft noise at home. The percentage severely annoyed children was predicted to increase from about 7% at 50 dB to about 15% at 60 dB; the percentage severely annoyed parents was predicted to increase from about 5% at 50 dB to about 17% at 60 dB. There was a significant difference in exposure-response gradient between the children and their parents ($\chi^2=18.7$, $df=2$, $p<0.0001$). At levels above 55 dB the percentage of severely annoyed children is lower than the percentage of severely annoyed parents, but below 45 dB the percentage of severely annoyed children is slightly higher than the percentage of severely annoyed parents.

TABLE II. Component loading matrix (N=2185) using Varimax rotation. (Only loadings >0.400 are shown. Loadings within "⟨ ⟩" were not used when interpreting the data. N is the sample size.)

	Component				
Item	I	II	III	IV	V
Annoyed road traffic at school		0.617			
Annoyed aircraft at school	0.740				
Annoyed road traffic at home					0.410
Annoyed aircraft at home	0.655				
Road traffic interferes play outdoors at school					0.665
Road traffic interferes group work at school		0.692			
Road traffic interferes own work at school		0.736			
Traffic interferes listening to teacher at school		0.699			
Aircraft interferes play outdoors at school	0.595				
Aircraft interferes group work at school	0.702				
Aircraft interferes own work at school	0.700				
Aircraft interferes listening to teach at school	0.691				
Road traffic interferes play outdoors at home					0.740
Road traffic interferes TV at home			0.701		
Road traffic interferes talking at home			0.635		
Road traffic interferes reading at home			0.685		
Aircraft interferes play outdoors at home					0.564
Aircraft interferes TV at home	⟨*0.539*⟩		0.575		
Aircraft interferes talking at home	0.571		⟨*0.504*⟩		
Aircraft interferes reading at home	0.565		⟨*0.558*⟩		
Headaches				0.610	
Vomiting				0.620	
Stomachache				0.579	
Difficult to sleep				0.590	
Times awake				0.641	
Sleepy in day				0.573	

Component	Interpretation	Variance explained	Alpha[a]
I	Disturbance and annoyance due to aircraft noise	32.471	0.89
II	Disturbance and annoyance due to road traffic noise at school	7.512	0.79
III	Interference from road traffic noise at home	6.220	0.77
IV	Health	5.225	0.67
V	Interference playing outdoors	4.843	0.69
Total		56.272	

[a]Cronbach's alpha (standardized): function of the item intercorrelation and the number of items included in the scale based on the items given in the component loading matrix.

IV. DISCUSSION

We found significant associations between aircraft and road traffic noise exposure and annoyance among school children living near three major European airports. This is consistent with results of previous studies investigating children's reactions to aircraft and road traffic noise,[13–18] which demonstrated that annoyance was significantly higher among children in high noise schools and areas compared with low noise schools and areas.

A. Measurement of children's annoyance

The results of the PCA show that children can make a clear distinction between annoyance and perceived health as measured by means of self-reported symptoms. As in adults,[23,24] the correlation found between annoyance and interference or disturbance of activities was high. This is consistent with the findings of a survey among 207 children (aged 13–14 years) investigating the effects of road traffic noise.[28] Our results are consistent with Haines and Stansfeld[29] investigating the effects of aircraft noise; they found that severely annoyed children agreed more often that "noise makes it hard to work" than children who were less annoyed. However, aircraft noise annoyance at school was not found to be associated with other aspects of classroom interference.

Our data suggest that the children were able to distinguish between indoors and outdoors rather than between school and home. This is clear from the grouping of items in Table II, where the items "road traffic interferes play out-

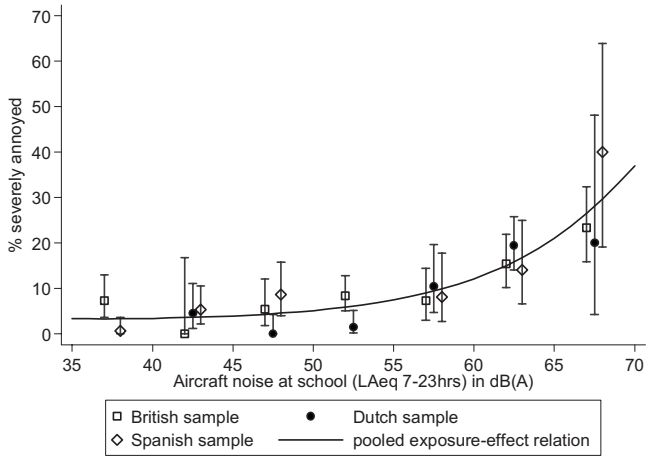

FIG. 1. The country-specific percentage severely annoyed children by 5 dB bands of aircraft noise ($L_{Aeq,7-23\ h}$) at school and the relationship between aircraft noise at school and the percentage of children severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.

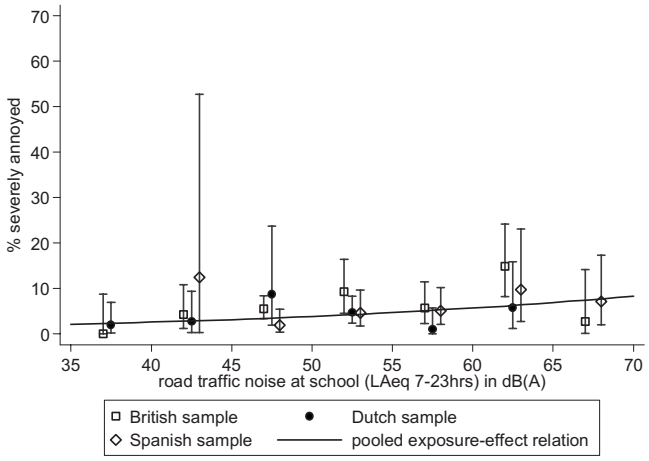

FIG. 3. The country-specific percentage severely annoyed children by 5 dB bands of road traffic noise ($L_{Aeq,7-23\ h}$) at school and the relationship between road traffic noise at school and the percentage of children severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.

doors at school," road traffic interferes play outdoors at home," and "aircraft interferes play outdoors at home" loaded high in the same component. Also, there was a clear distinction between annoyance from aircraft and road traffic noise, but not between annoyance from aircraft noise at school and at home. The latter result was not the case for road traffic noise. The observed high correlation between annoyance from aircraft noise at school and at home is consistent with the distribution of aircraft noise exposure levels: aircraft noise levels at school and at home were also highly correlated in each of the countries ($r \sim 0.85-0.93$).[30] Since primary schools are usually located in the residential area of the child, we expect a great similarity in exposure levels between the school and home situations. Children aged 9–12 years appear to be able to discriminate their annoyance responses to road and aircraft noise sources and are consistent in their annoyance responses to aircraft noise across contexts such as school and home. Our results also indicate that children clearly distinguish between sources of noise as well as between annoyance and other indicators of well-being.

B. Annoyance reactions to aircraft and road traffic noise

After pooling the data, noise exposure levels of both aircraft and road traffic were significantly related to the percentage of severely annoyed children. No significant differences were found in the fraction severely annoyed at different exposure levels between countries. This is different from the variability earlier observed in a review evaluating studies that investigated adults' noise annoyance reactions.[31]

Another finding of our study was that the association with annoyance in children is stronger for aircraft than for road traffic noise, similar to adults. First, it is likely that aircraft noise has a greater effect on children's annoyance reactions than road traffic noise amongst others because of

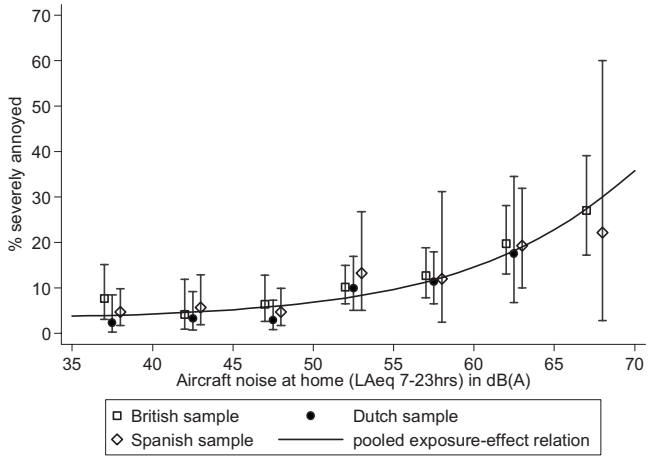

FIG. 2. The country-specific percentage severely annoyed children by 5 dB bands of aircraft noise ($L_{Aeq,7-23\ h}$) at home and the relationship between aircraft noise at home and the percentage of children severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.

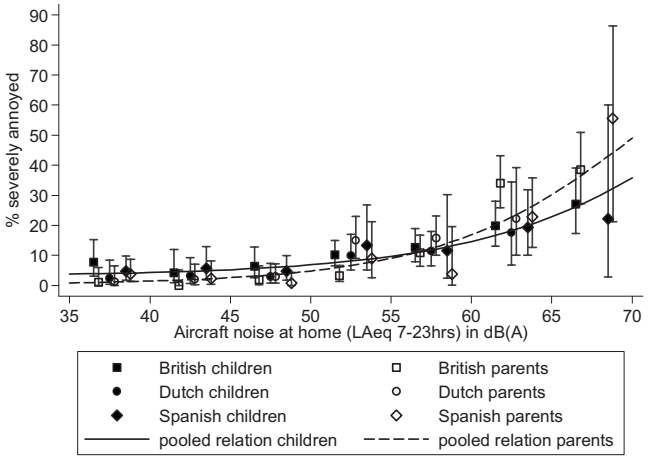

FIG. 4. Comparison between children and their parents: the country-specific percentage severely annoyed children and parents by 5 dB bands of aircraft noise ($L_{Aeq,7-23\ h}$) at home and the relationship between aircraft noise at home and the percentage of children and parents severely annoyed derived after pooling the data and adjustment for confounders. The vertical lines correspond to the 95% confidence interval.

its intensity, its variability, and unpredictability in comparison with road traffic noise.[1,32] Second, exposure misclassification may also have occurred because classrooms were at varying distance from the façade of the school building.[30] A third possible explanation is that the combined exposure to aircraft noise and road traffic noise might have affected children's annoyance response: children in high aircraft noise areas might report more annoyance from aircraft noise in high road traffic noise areas than children in low road traffic noise areas and vice versa. Fourth, differences in school systems and teachers' attitudes and/or responses toward noise might have differential effects on the children's reactions to noise sources at school. There might be differences in frequency and type of insulation of both schools and homes, which could result in different annoyance reactions, even though both design and analysis accounted for the influence of insulation. Finally, with the current available methods and data it is more dubious to predict road traffic noise exposure accurately. Different countries use different methods for the CRTN exposure. Previous comparisons of different national calculation methods for certain road traffic situations revealed that differences up to 15 dB may exist.[33] However, since the exposure-response functions for annoyance did not differ much between countries, this seems to indicate that the different methods for assessing the exposure were robust enough in the RANCH study. Unfortunately, most of these possible explanations cannot be further investigated with the RANCH data.

C. Annoyance reactions of children and parents

In general, the exposure-response relationships of children and their parents display a comparable trend in spite of some significant differences: children have lower response frequencies of severely annoyed than their parents at higher noise levels. This is consistent with earlier findings from the Tyrol Mountains study[18] which investigated the relationship between road and rail traffic noise and annoyance in children and their parents.

Possible explanations for the difference between children and adults' annoyance response to noise could be sought in nonacoustical factors[34] such as noise sensitivity, attitudes toward the noise source, perceived control, expectations, and coping behavior. Boman and Enmarker[35] observed that teachers were more annoyed due to road traffic noise than children and perceived the noise of road traffic noise to be more unpredictable than their pupils. In addition, the teachers described themselves as more sensitive to noise than the children. Conversely, teachers perceived more personal control over the noise than did the children. Unfortunately, the RANCH data do not enable us to analyze the influence of such nonacoustical factors.

The observation that children have significantly lower responses than their parents at higher noise levels could also mean that children are more sensitive at lower noise levels and that children's annoyance at higher noise levels is less influenced by nonacoustical factors than the annoyance of adults. To what extent this is the case for children cannot be determined based on the RANCH data.

D. Strengths and limitations

This study represents an improvement on previous studies[12–19] due to its large sample size both in the number of participants and number of schools. Despite the heterogeneity of the countries, results for noise and annoyance were rather similar across the three countries; i.e., we noted cross-cultural replication of the findings. A further strength of this study is the comprehensive inclusion of potential confounders and determinants. The hierarchical structure of the data (children within schools) has been taken into account, which was not the case in analyses of previous studies. The participants were distributed over a broad exposure range, and a continuous noise exposure measure was used, adding to the statistical power of the study. Most studies investigating the impact of noise exposure have involved between-group comparisons (high versus low): results of these studies may be sensitive to decisions about cutoff points used to categorize continuous exposure variables and the method used to assign scores to exposure categories.[36]

As already indicated the estimation of exposure to road traffic noise remains problematic: during their time at school, road traffic noise exposure changes as children move to a different classroom each year. Thus, the road traffic noise levels at the façade of their current classroom might not reflect the average level of exposure during their time at school.

E. Implications

The WHO guidelines for noise suggest that children are more sensitive to noise than adults because they are exposed to noise during critical developmental periods.[1] Children may also have fewer possibilities for controlling noise or have a less developed coping repertoire than adults.[5] However, we found that the exposure-response relationships for children were broadly comparable to those for their parents; if anything, the frequencies of severe annoyance at high exposures were lower among the children. Furthermore, annoyance is not the only indicator of the impact on children's health and well-being due to community noise. As demonstrated in the different publications of the RANCH study, cognitive,[25,30] behavioral,[37] and physiological measures[38–40] are necessary to fully describe the impact of environmental noise on children. For annoyance, the WHO guidelines recommend a L_{Aeq} of 55 dB for noise from external sources outdoors at school during play and for noise outdoors in the living area.[1] Our results (Figs. 1 and 2) indicate that some children were already severely annoyed due to aircraft noise at home and at school at lower levels ($L_{Aeq,7–23.outdoors}$ 45 dB), which suggests that the WHO community guideline values should be lowered to protect these children.

V. CONCLUSIONS

Children's annoyance can be reliably measured within a questionnaire. Exposure-response relationships were demonstrated between aircraft and road traffic noise exposure and severe annoyance among primary school children. Although

children were less annoyed at levels above 55 dB, these relationships were broadly comparable to those among their parents.

ACKNOWLEDGMENTS

Funding was provided by the European Community (QLRT-2000-00197), DEFRA in the UK, the Dutch Ministries of VROM, VWS, and VW. We thank the children, their parents, and the schools, our colleagues at RIVM, Queen Mary, and CSIC for helping with collecting the data, and the other members of the RANCH team for their consultation about the study. None of the authors have any competing financial interests.

[1]World Health Organization, *Guidelines for Community Noise*, edited by B. Berglund, T. Lindvall, D. H. Schwela, and K. T. Goh, World Health Organization, Geneva, 1999.
[2]R. F. S. Job, "Noise sensitivity as a factor influencing human reactions to noise," Noise Health **3**, 57–68 (1999).
[3]R. Guski, U. Felscher-Suhr, and R. Schuemer, "The concept of noise annoyance: How international experts see it," J. Sound Vib. **223**, 513–527 (1999).
[4]J. M. Fields, R. G. deJong, T. Gjestland, I. H. Flindell, R. F. S. Job, S. Kurra, P. Lercher, M. Vallet, T. Yano, R. Guski, U. Felscher-Suhr, and R. Schumer, "Standardized general purpose noise reaction questions for community noise surveys: Research and recommendation," J. Sound Vib. **242**, 641–679 (2001).
[5]M. L. Bistrup, "Prevention of adverse effects of noise on children," Noise Health **5**, 59–65 (2003).
[6]T. J. Schultz, "Synthesis of social surveys on noise annoyance," J. Acoust. Soc. Am. **64**, 377–405 (1978).
[7]S. Fidell, D. S. Barber, and Th. J. Schultz, "Updating a dosage-effect relationship for the prevalence of annoyance due to general transportation noise," J. Acoust. Soc. Am. **89**, 221–233 (1991).
[8]L. S. Finegold, C. S. Harris, and H. E. von Gierke, "Community annoyance and sleep disturbance: Updated criteria for assessing the impacts of general transportation noise on people," Noise Control Eng. J. **42**, 25–30 (1994).
[9]H. M. Miedema and H. Vos, "Exposure-response relationships for transportation noise," J. Acoust. Soc. Am. **104**, 3432–3445 (1998).
[10]H. M. E. Miedema and H. Vos, "Noise annoyance from stationary sources: Relationships with exposure metric day-evening-night level (DENL) and their confidence intervals," J. Acoust. Soc. Am. **116**, 334–343 (2004).
[11]H. M. E. Miedema and C. G. M. Oudshoorn, "Annoyance from transportation noise: Relationships with exposure metrics, DNL and DENL and their confidence intervals," Environ. Health Perspect. **109**, 409–416 (2001).
[12]P. Lercher, "Annoyance, disturbance and severances in children exposed to transportation noise," in *Proceedings of the Eighth International Congress on Noise as a Public Health Problem*, 29 June–3 July 2003, edited by R. G. de Jong, T. Houtgast, E. A. M. Franssen, and W. Hofman, (International Commission on Biological Effects of Noise, Rotterdam, The Netherlands, 2003), pp. 241–248.
[13]G. W. Evans, S. Hygge, and M. Bullinger, "Chronic noise and psychological stress," Psychol. Sci. **6**, 333–338 (1995).
[14]G. W. Evans, M. Bullinger, and S. Hygge, "Chronic noise exposure and physiological response: A prospective study of children living under environmental stress," Psychol. Sci. **9**, 75–77 (1998).
[15]M. M. Haines, S. A. Stansfeld, R. F. S. Job, B. Berglund, and J. Head, "Chronic aircraft noise exposure, stress responses, mental health and cognitive performance in school children," Psychol. Med. **31**, 265–277 (2001).
[16]M. M. Haines, S. A. Stansfeld, S. Brentnall, J. Head, B. Berry, M. Jiggins, and S. Hygge, "The West-London School Study: The effects of chronic aircraft noise exposure on child health," Psychol. Med. **31**, 1385–1396 (2001).
[17]M. M. Haines, S. A. Stansfeld, R. F. S. Job, B. Berglund, and J. Head, "follow-up of chronic aircraft noise exposure on child stress responses and cognition," Int. J. Epidemiol. **30**, 839–845 (2001).
[18]P. Lercher, G. Brauchle, W. Kofler, U. Widmann, and M. Meis, "The assessment of noise annoyance in schoolchildren and their mothers," in *Proceedings of the 29th International Congress and Exhibition on Noise Control Engineering*, 27–30 August 2000, edited by D. Casserau (Société Française d'Acoustique, Nice, France, 2000), Vol. **4**, pp. 2318–2322.
[19]H. Sukowski, M. Meis, P. Lercher, D. Heydinger, and A. Schick, "Noise annoyance of children exposed to chronic traffic noise: Results from the Tyrol School Study II," in *Contribution to Psychological Acoustics: Results of the eighth Oldenburg Symposium on Psychological Acoustics*, edited by A. Schick, J. Hellbrück, H. Höge, M. Klatte, G. Lazarus-Mainka, M. Meis, C. Reckhardt, K. P. Walcher, and R. Weber Bibliotheks—und Informationssystem der Universiät Oldenburg, 2000, pp. 571–580.
[20]B. Berglund, T. Lindvall, and M. E. Nilsson, "The children's community response to environmental noise," Revista de Acústica **38**, Paper ENV 02-003(2007).
[21]ISO/TS 15666, *Acoustics—Assessment of noise annoyance by means of social and socio-acoustic surveys*, International Organization for Standardization, Geneva, Reference No. ISO/TC 43/SC 1 N 1313, 2003.
[22]M. M. Haines, S. L. Brentnall, S. A. Stansfeld, and E. Klineberg, "Qualitative responses of children to environmental noise," Noise Health **5**, 19–30 (2003).
[23]I. van Kamp, A. E. M. Franssen, and R. G. de Jong, "Indicators of annoyance: A psychometric approach; the measurement of annoyance and interrelations between different measures," in *The 2001 International Congress and Exhibition on Noise Control Engineering* (Acoustical Society of The Netherlands, The Hague, The Netherlands, 2001), pp. 27–30.08.
[24]I. van Kamp, *Coping With Noise and Its Health Consequences* (Styx & pp, Groningen, 1990).
[25]S. A. Stansfeld, B. Berglund, C. Clark, I. Lopez-Barrio, P. Fischer, Ohrström, E., M. M. Haines, J. Head, S. Hygge, I. van Kamp, and B. F. Berry, "Aircraft and road traffic noise and children's cognition and health: A cross-national study," Lancet **365**, 1942–1949 (2005).
[26]*Calculation of Road Traffic Noise (CRTN)*. (HSMO, London, 1998).
[27]A. G. Dassen, J. Jabben, and J. H. J. Dolmans, "Development and use of EMPARA: A model for analysing the extent and effects of local environmental problems in the Netherlands," in *The 2001 International Congress and Exhibition on Noise Control Engineering*, (Acoustical Society of The Netherlands, The Hague, The Netherlands, 2001), pp. 27–30.08.
[28]I. Enmarker, and E. Boman, "Noise annoyance responses of middle school pupils and teachers," J. Environ. Psychol. **24**, 527–536 (2004).
[29]M. Haines, and S. Stansfeld, "Measuring annoyance and health in child social surveys," in *The 2000 International Congress and Exhibition on Noise Control Engineering*, (Société Française d'Acoustique, Nice/France, 2000).
[30]C. Clark, R. Martin, E. van Kempen, T. Alfred, J. Head, H. W. Davies, M. M. Haines, I. Lopez-Barrio, M. Matheson, and S. A. Stansfeld, "Exposure-effect relations between aircraft and road traffic noise exposure at school and reading comprehension. The RANCH project," Am. J. Epidemiol. **163**, 27–37 (2006).
[31]R. Guski, "How to forecast community annoyance in planning noisy facilities," Noise Health **6**, 59–64 (2004).
[32]European Commission Working Group Assessment of Exposure to Noise (WG-AEN), "Good practice guide for strategic noise mapping and the production of associated data on noise exposure," Position paper, Version **2**, 13 August 2007, Report No. WG-AEN 004.2007. doc, available at http://ec.europa.eu/environment/noise/pdf/gpg2.pdf. Last viewed 1/9/2009.
[33]H. A. Nijland and G. P. van Wee, "Traffic noise in Europe: A comparison of calculation methods, noise indices and noise standards for road and railroad traffic in Europe," Transport Rev. **25**, 591–612 (2005).
[34]P. J. M. Stallen, "A theoretical framework for environmental noise annoyance," Noise Health **3**, 69–79 (1999).
[35]E. Boman, and I. Enmarker, "Factors affecting pupils' noise annoyance in schools: The building and testing of models," Environ. Behav. **36**, 207–228 (2004).
[36]D. B. Richardson and D. Loomis, "The impact of exposure categorisation for grouped analyses of cohort data," J. Occup. Environ. Med. **61**, 930–935 (2004).
[37]S. A. Stansfeld, C. Clark, R. M. Cameron, M. M. Haines, I. van Kamp, E. van Kempen, and I. Lopez-Barrio, "Aircraft and road traffic noise exposure and children's mental health in the RANCH study," in *Proceedings of the 33rd International Congress and Exposition on Noise Control Engineering*, 22–25 Aug. (Czech Acoustical Society, Prague, 2004).
[38]E. van Kempen, I. van Kamp, P. Fischer, H. Davies, D. Houthuijs, R. Stellato, C. Clark, and S. Stansfeld, "Noise exposure and children's blood

pressure and heart rate: The RANCH-project," J. Occup. Environ. Med. **63**, 632–639 (2006).
[39]A. G. Gunnarsson, B. Berglund, M. Haines, M. E. Nilsson, and S. A. Stansfeld, "Psychological restoration in noise-exposed children," *Proceedings of the eighth International Congress on Noise as a Public Health Problem*, 29 June–3 July 2003. (International Commission on Biological Effects of Noise, Rotterdam, 2003), pp. 159–160.
[40]E. Öhrström, E. Hadzibajramovic, M. Holmes, and H. Svensson, "Effects of road traffic noise on sleep: Studies on children and adults," J. Environ. Psychol. **26**, 116–126 (2006).